An Operational Comparison of DEA Versus Formulated High Performance Selective Amine Technology

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Abstract

This presentation will illustrate a direct comparison of DEA versus a formulated selective MDEA solvent (HS-115) loaded under similar operating conditions. Also included is a description of the conversion process, facility modifications, projected and actual benefits. Finally, the results of an on-line performance test at maximum rates will be reviewed.

Introduction

The Brazeau River Gas Plant (LSD 3-12-46-14-W5M) is a sour gas processing facility with an inlet design capacity of 220 MMscfd. The facility is located approximately 170 Kilometers southwest of Edmonton, Alberta (Figure #1 included in attachments displays a regional map with facility location). Gulf Canada is the plant operator and there are seven owners.

The Brazeau River Gas Plant amine system consists of two identical trains (plant #1 & #2) each designed to process approximately 110 MMscfd each (Figure #2 included in attachments displays a process flow schematic for a typical amine train). The original gas treating process was a conventional amine system employing a 22 wt% DEA solution.

The plant was constructed in 1968 as a single train with an inlet design capacity of 73 MMscfd of dry Elkton-Shunda gas. Original discovery was the Brazeau River Gas Unit containing 1.35 % H_2S & 12 bbl condensate/MMscfd.

In 1972, a second processing train capable of processing a further 83 MMscfd of Elkton-Shunda gas was added. In 1978 a de-bottleneeking project was completed to increase the plant design capacity to 220 MMscfd (110 MMscfd per train) in winter and approximately 194 MMscfd in summer conditions (96 MMscfd and 98 MMscfd for trains #1 & #2 respectively).

Each processing train has an arnine sweetening and sulphur recovery unit. Each sulphur plant consists of a split flow, two converter Claus unit designed to process 60 tonnes/day. The minimum licensed sulphur recovery is 92.1%. The plant process is controlled by a Fisher Rosemount distributed control system.

Process heat is supplied by a hot oil heat transfer fluid.

The plant #1 amine system was converted from DEA to a formulated high performance MDEA based solvent on October 4, 1996. Benefits from the amine conversion project include the following:

- Reduced fuel gas consumption resulting from decreased amine regeneration reboiler duty.
- Reduced electrical demand on amine circulation pumps, amine regeneration overhead condensers and lean amine coolers.
- Improved sulphur plant performance due to enriched acid gas feed.
- Increased gas processing capacity. The results from an on-line performance test at maximum rates operating with new formulated amine will be discussed.

The second amine plant was converted to the same formulated MDEA on April 14, 1997, following a successful comparison of this solvent versus DEA loaded under identical operating conditions.

MDEA Chemistry

Methyldiethanolamine (MDEA) based sweetening solvents have received a great deal of attention because the capability for "selective" reaction with H_2S in the presence of CO_2. Selective gas treating refers to the preferential removal of hydrogen sulphide from a sour gas stream while rejecting most of the accompanying CO_2 or delaying the recovery of CO_2 until a subsequent processing step. Selective treatment using chemical solvents is usually based on the more rapid pickup of H_2S compared to CO_2. Thus, the contact time between the solvent (MDEA) and sour gas is limited to permit removal of the H_2S only to the degree required and then to stop the contact so that only minimum co-absorbtion of CO_2 occurs. Increased selectivity for H_2S over CO_2 expands the regeneration capacity of an amine unit, reduces the energy required for treating and improves the H_2S quality of the acid gas.

The selectivity of MDEA and related solvents can be influenced by:

1. Contact temperature - colder processing (less than 90°F) or hotter processing (greater than 120°F) results in improved selectivity.
2. Contact pressure - lower pressures improve selectivity.
3. Feed gas CO_2/ H_2S ratio - higher ratios of CO_2 to H_2S favor selectivity.
4. Total acid gas loading.
5. Location of lean amine feed point on contactor tower.

MDEA based solvents have numerous advantages over primary amines (MEA and DGA) and secondary amines (DEA):

- Selectively removing H_2S from gas stream, while kinetically limiting CO_2 absorption. Amine selectivity will enrich acid gas feed to the sulphur plant, increasing sulphur plant efficiency & capacity. (reference #1).
- Less degradation. Unlike MEA, DEA and DGA, MDEA does not form amine CO_2 degradation products which can enhance corrosion at elevated temperatures in the regenerator (reference #1 & #5).
- Less corrosion. MDEA have a lower corrosion rate than MEA, DEA and DGA (reference #1 & #5).
- Lower amine reboiler duty. The heat of reaction for the H_2S and $C0_2$ combination found at the Brazeau River Gas Plant is about 30% lower than for DEA. The lower amine circulation rate and heat of reaction combine to provide reduced amine reboiler duty (reference #1). Heats of reaction for H_2S and CO_2 for various pure amines are discussed in reference #6.
- Solvent losses are reduced due to lower MDEA vapor pressure. Typically DEA losses are 4 lb/MMscf and MDEA losses are 1-1 1/2 to 2 lb/MMscf.
- Lower amine circulation rate and pumping horsepower. Acid gas pickup of up to 0.5 mole/mole MDEA is available without a need to consider costly metallurgy upgrades (reference #1 & #5).

Arnine solvent concentration is usually limited by corrosion considerations. MEA concentration is limited to 15 to 20 wt% due to its primary amine characteristics. DEA is a secondary amine and its operating concentration is limited to 30 wt%. MDEA based solvents can operate at much higher concentrations with low corrosion potential. Considerable additional treating capacity is available with the formulated MDEA solvents by increasing the weight strength to 50 wt% (reference #6).

MDEA Chemistry cont.

Finally, the desirable characteristics of basic MDEA, depending on application, have been extended by various manufacturers through the addition of chemical enhancers to create high performance formulated MDEA based products.

Plant Configuration & Operation

At time of comparison the plant #1 amine system circulated a 40 wt % formulated MDEA solvent, slipping approximately 1.5 mole % CO_2 to sales gas stream. The plant #2 amine system was circulating a 30 wt % DEA solution. The feed to both amine trains contained approximately 3.2 mole % CO_2 and 1.2 mole % H_2S. The original plant design ratio of CO_2/H_2S was 3.15, as compared to 2.75 at time of conversion. The following table includes a comparison of raw gas composition feeding amine contactors from original plant design and at time of conversion.

Table #1. - Comparison of Original Plant Design Versus Current Raw Gas Composition

	Brazeau River Gas Unit Original Design (Mole %)	Operation 17-Mar-97 (Mole %)
N2	0.12%	0.25%
CO2	4.25%	3.24%
H2S	1.35%	1.18%
C1	87.77%	84.91%
C2	3.75%	6.08%
C3	0.94%	2.34%
IC4	0.25%	0.44%
NC4	0.29%	0.74%
IC5	0.14%	0.23%
NC5	0.12%	0.23%
C6	0.27%	0.16%
C7+	0.75%	0.20%
Total:	100%	100%
CO2/H2S Ratio:	3.15	2.75

A maximum design outlet gas specification from amine contactor of 16 ppm H_2S and 2 mole % CO_2 was used. The following table includes the design sales gas specifications.

Table #2. – Sales Gas Design Specifications

H2S Content (grains/100CF):	0.25 (16 ppm H_2S)
Mercaptan Content (grains/100 CF):	0.20
Total Sulphur (grains/100 CF):	1.0
CO_2 Content (mole %):	2
Hydrocarbon Dew Point (Deg F):	15 F @ 800 psia
Water Content (lbs/MMscf):	4

The configuration of plant #1 and #2 amine trains are similar with the following exceptions:

- Plant #1 utilizes a pressurized surge drum, whereas plant #2 utilizes an atmospheric surge drum.

- The size of plant #1 and #2 contactors are identical (72" I.D. x 52'0" T/T c/w 20 trays), however the tray types are different. Plant #1 contactor (PV-17.03) is constructed with Glitsch perforated truss-type (sieve) trays, whereas plant #2 contactor (PV- 17.52) is constructed with Glitsch truss-type ballast (valve) trays.

Plant Configuration & Operation cont.

The estimated maximum capacities of the amine contactors are as follows:

	Raw Inlet:
Plant # I - PV- 17.03 (Sieve Trays)	94.0 MMscfd
Plant #2 - PV- 17.52 (Valve Trays)	112.5 MMscfd (on-line performance test confirmed 124 MMscfd)

Table #5 and #6 included in attachments, summarize the operation of both amine trains, illustrating a direct comparison of UCARSOL® HS-115 and DEA solvents.

System Preparation

To ensure effective operation after conversion to a formulated MDEA solvent, the following facilities were installed:

- **Rich Amine Filtration**

A full flow rich amine bag filter was added to each sweetening train. Polypropylene bags were used in each rich filtration unit. The amine filtration system was added to increase capability to remove suspended solids. The removal of suspended solids in amine solution is required to prevent foaming, erosion and corrosion. Foaming in amine systems is typically caused by the following contaminants (reference #1):

- Lubrication oils
- Dissolved liquid hydrocarbons
- Valve Greases
- Well treating chemicals
- Fine suspended particles entering the system such as iron sulfide and iron oxide. Iron sulphide is removed in rich stream through full flow rich filtration.
- Corrosion inhibitors
- Excessive antifoam agents

Based on operational experience, MDEA based solvents appear to have a similar foaming tendency when compared to DEA. After an upset (i.e. foaming) the full flow rich bag filtration can clean the amine system in approximately 12 hours compared to one week with original 10 lean filtration facility. After an upset 25μ nominal bags are used for cleanup and 10μ nominal bags are used for normal day-to-day operation.

- **Carbon Filtration**

An activated carbon filter was installed to remove impurities from the lean amine solution. Filtration of amine solution through activated carbon bed will achieve the following objectives:

- Control foaming in both absorber and in the regenerator.
- Prevent loss of production due to H_2S specification problems.
- Reduce solvent losses.
- Maintain operational reliability.

System Preparation cont.

A 48" O.D. x 12'0" S/S activated carbon filtration vessel was installed common to both amine systems. The activated carbon filtration vessel was located on a lean amine slip stream (designed to handle 10% of entire amine solution flow) downstream of the existing lean amine particulate filter. A bag filter was installed downstream of carbon filter to remove fines. The design of carbon filter was based on the following parameters:

- 10~20% slip stream
- Vessel diameter 4 USGPM/ft^2
- 20~30 Minutes empty bed contact time.
- Vessel height 1.5 time the carbon height.

The carbon filtration vessel was located downstream of the lean amine mechanical filter to prevent fines from accumulating in the upper portion of the activated carbon bed.

- **Inlet Separation (Cyclone Separators)**

Cyclone separators were installed on the inlet of each amine train to remove fine liquids (primarily compressor lube oil). The purpose of the separator is to remove all hydrocarbon liquid carryover from the gas prior to entering the amine contactor. Hydrocarbon liquids in the amine solution will have a tendency to cause foaming. The addition of inlet separation was also intended to extend life of the sulphur catalyst by reducing hydrocarbon contamination in amine solution. The cyclone separators were designed to remove 99.9% of all free liquids and solids 5μ and larger.

All inlet gas at the plant is boosted through reciprocating compression. As a result, trace lube oil has been found present in amine solution after passing through the cyclone separation. Based on experience to date, it is recommended to install coalescer filters rather than cyclone separation on an inlet to amine system. The design of an inlet coalescer should remove lube oil, which particle sizes are typically in the order of 1 to 10μ in a fine mist (reference #4). Coalescing filters were not installed at the Brazeau River Gas Plant due to a negative experience operations encountered on a previous installation.

- **Sales Gas CO_2 Analyzer**

An on-line analyzer was added to monitor CO_2 slip to sales. The analyzer installed was a Siemens Ultramat 21 infrared CO_2 analyzer. The analyzer was intended to be an on-line tool for optimizing operation of amine system. The following parameters can be adjusted to increase CO_2 slip to sales and optimize operation of amine system:

- Lean amine circulation
- Inlet gas and lean amine temperature
- Hot oil to regenerator (adjust stripping of rich amine solution) as circulation rates are adjusted.

The H_2S content of sales gas stream was monitored by tying a 4-20 mA signal from the Nova meter station analyzer into the plant DCS system.

Conclusions

UCARSOL® HS-115 solvent was chosen for this application because it could provide much greater CO_2 slip than other MDEA based solvents (i.e. compared to HS-101). The benefits of replacing the DEA solvent with a formulated MDEA solvent are as follows:

- **Reduced fuel gas consumption** resulting from decreased amine regeneration reboiler duty **(savings approximately $278,200/year based on both processing trains).**
- **Reduced electrical demand** on amine circulation pumps, amine regeneration overhead condensers and lean amine coolers (**savings approximately $41,800/year based on both processing trains)**. Approximately 90% of electrical savings result from shutting down of one high pressure amine pump on each train.
- The acid gas flow to the sulphur plant was reduced by approximately 20%. This now provides for even longer catalyst life and greater sulphur plant capacity. Also, the feed to sulphur plant was enriched from approximately 21.5 mole % to 32 mole % H_2S (at 32 mole % H_2S content in acid gas the CO_2 conntent in sales gas is approximately 1 mole % representing a conservative estimate).
- **Reduced sulphur plant incinerator fuel gas consumption (savings approximately $11,400/year)**. Both sulphur plants utilize a common incinerator (HT- 15.56).
- The lean amine cooler limitations in the summer were eliminated. This provided for new extra processing capacity in warmer periods of the year.
- Overall gas processing capacity with UCARSOL® HS-115 is expected to be 4~5% greater than with UCARSOL® HS-101 (a solvent much closer to pure MDEA in performance).

The total estimated operating cost savings as a result of the project are $331,400/year for both amine plants. Table #7 included in attachments provides a detailed estimate of cost savings.

The following table outlines percent change in specific variables comparing operation of DEA to formulated MDEA (data is based actual measurements from table #6).

Table #3. - Percent Change in Specific Variables Comparing Operation of DEA to Formulated MDEA

	Actual:	Anticipated:
CO2 to Sales:	1.00%	1.77%
Lean Amine Circulation Rate:	22%	29%
Acid Gas Flow:	20%	35%
Regen. Reboiler Duty:	29%	39%
Lean Amine Cooler Duty:	11%	34%
Reflux Condenser Duty:	22%	56%

Unexpected Performance Test

On May 19, 1997 the plant #1 direct fired hot oil medium heater (HR-15.01) at the Brazeau River Gas Plant was destroyed in an explosion and created an extraordinary opportunity to test the maximum performance of the formulated MDEA. There were no personnel injuries associated with the accident. The cause was determined to be an electrically activated solenoid valve which failed in the open position, thus allowing fuel gas to enter the heater cabin. Operating at reduced rates, the plant was back on-line three hours after the incident, processing exclusively through the plant #2 amine system. Performance of the plant #2 amine system during this period can be described as follows:

Unexpected Performance Test cont.

Table #4. - Operating Conditions For Plant #2 After Hot Oil Heater Failure Compared to Normal Operation

	Plant #2 Max. Gas Rates			Plant #1 Normal	
	30-Jun-97	26-Jun-97	12-Jun-97	17-Mar-97	
Inlet Gas Rate:	3,183	3,139	3,181	1,907	E3m3/d
Inlet Gas Temperature:	28.5	29.5	26.8	28.3	C
Sales H2S:	3	3	10 ~~3~~	2~4	ppm
Sales CO2:	1.8	1.8	1.8	1.5	mole %
Contactor Differential:	53.6	51.9	55.3		kPa
Amine Circulation:	93	93.6	84.2	82	m3/h
Lean Amine Strength:	29.5	27.5	30.1	40.8	%
Lean Loading:	0.01	0.01	0.01	0.008	moles CO2/mole amine
Rich Loading:			0.44(*)	0.38	moles Acid Gas/mole amine
Regen. Btms. Temp.:			113	113	C
Regen. Ovhd Temp.:			14.3		C
Regen. Ovhd. Press.:			51.3	34.5	kPa
Regen. Differential:			31.2		kPa
Regen. Reflux Flow:			5.9	3.5	m3/h
Regen. Duty:			44.8	26.5	MMBtu/h

(*) The rich loading on June 12 was measured by on-site lab.

A plant mass balance based on measured values of 98 E3m^3/d of acid gas and 43 tonnes/day of sulphur production on June 12, results in a calculated H_2S inlet concentration of 1.0 mole % by volume, a CO_2 inlet concentration of 3.7% by volume and a rich solvent loading of a little over 0.8 moles of acid gas per mole of solvent.

Unless the hot rich system of the amine plant is designed for handling two phase flow and the resultant high velocities *operating a rich solvent loading in the range of 0. 8 mole acid gas per mole amine is clearly not recommended as an on-going operating practice.*

A maximum raw inlet rate of 124 MMscfd was processed through the plant #2 amine system for a short period (approximately 12 hours). An important fact to note is the calculated maximum rate for the high pressure contactor (PV-17.52) was 112.5 MMscfd. The limitations encountered were amine carryover and pressure drop through contactor & exchangers in downstream chilling facilities ($\Delta P_{system} \equiv 120$ psid). The CO_2 slip during this period was maximized at 2 mole % and sales gas H_2S content was 10 ppm.

The replacement plant #1 hot oil heater was installed and on-line approximately one month after the incident.

Comparing production from table #4 above and maximum design circulating DEA, an estimate of $438,100 incremental revenue was achieved as a result of the conversion to a high performance amine during this period. It is also important to note the maximum design rate of 110 MMscfd was never historically achieved circulating DEA through the plant #2 amine system (i.e. plant would go sour).

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Corporate Disclaimer

Attachments

Figure #1.- Regional Map Showing Plant Location.

Figure #2. - Process Flow Schematic for Typical Amine Train

Table #5. - Comparison of Design, Performance and Simulation Results.

Table #6. - Direct Comparison of Plant #1 & #2 Amine System Overation.

Table #7. - Estimated Cost Savings as a Result of Conversion from DEA to Formulated MDEA.

Table #8. - Anticipated Versus Actual Process Changes (DEA Versus Formulated MDEA).

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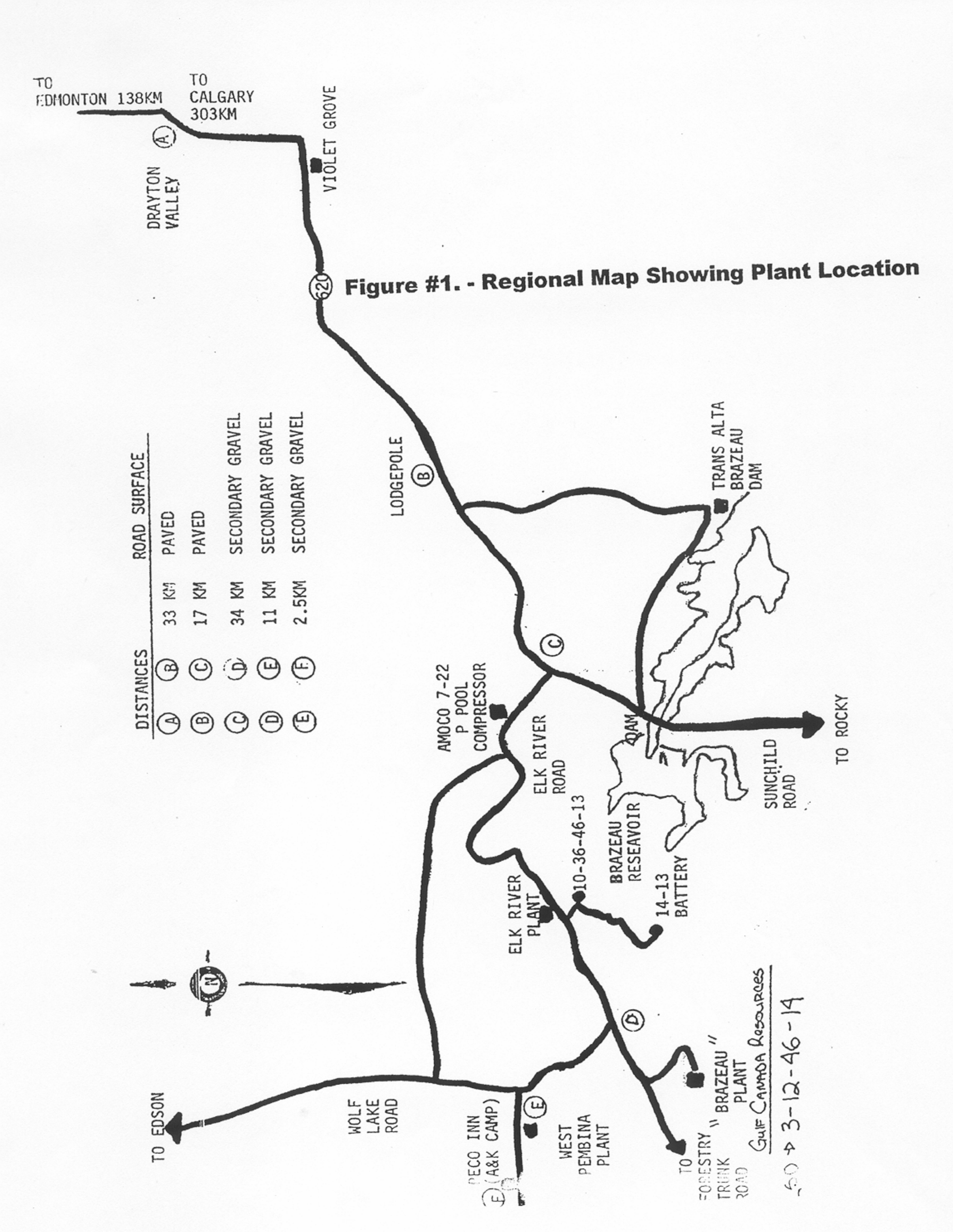

Figure #1. - Regional Map Showing Plant Location

Basic Brazeau Plant Schematic

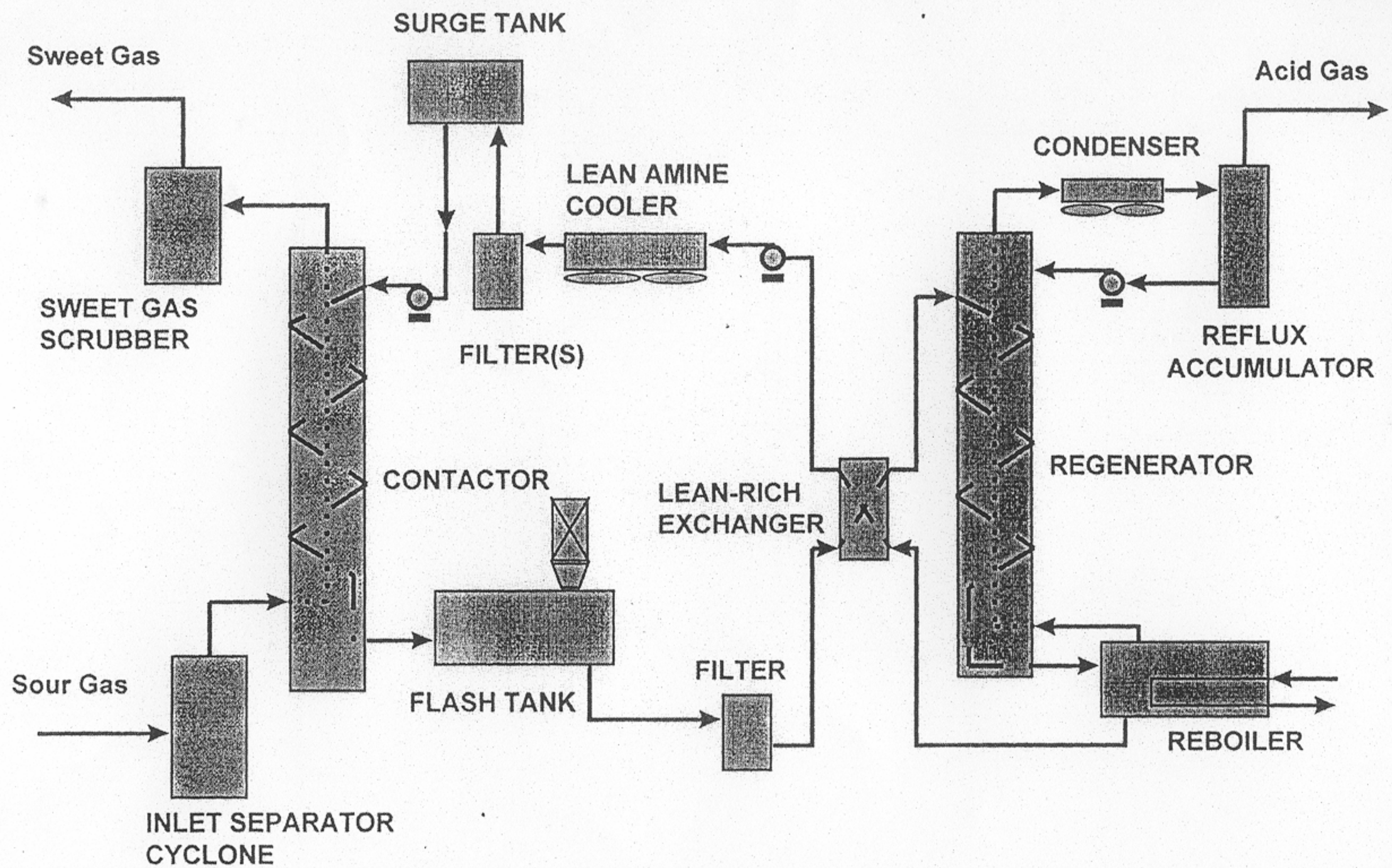

Figure #2. - Process Flow Schematic for Typical Amine Train

Table #5. - Comparison of Design, Performance and Simulation Results

Absorber Feed Gas Conditions:						
Date:	17-Mar-97	17-Mar-97	07-Mar-96	07-Mar-96	07-Mar-96	07-Mar-96
Rate (MMscfd):	67.4	67.4	60	60	60	60
Temperature (F):	83	83	90	90	90	86
Pressure (psig):	917	917	910	910	910	910
Inlet Gas Composition (Mole Percent):						
N2	0.25%	0.25%	0.3%	0.3%	0.3%	0.3%
CO2	3.24%	3.24%	3.8%	3.8%	3.8%	3.7%
H2S	1.18%	1.18%	1.0%	1.0%	1.0%	1.0%
C1	84.90%	84.90%	86.3%	86.3%	86.3%	86.2%
C2	6.08%	6.08%	5.2%	5.2%	5.2%	5.2%
C3+	4.35%	4.35%	3.4%	3.4%	3.4%	3.5%
Total:	100%	100%	100%	100%	100%	100%
	Plant #1 Amine Train Operation		Orignal Design Basis			
	UCARSOL HS-115	UCARSOL HS-115	UCARSOL HS-115	UCARSOL HS-101	DEA	DEA (AMSIM)
Solution Conditions:	(From Simulation)	(Actual Performance)	(From Simulation)	(From Simulation)	(Actual Performance)	From Simulation)
Circulation Rate (m3/h):	84.9	82.0	72.2	75.2	102.0	102.1
Circulation Rate (USGPM):	374	361	318	331	449	450
Amine Strength (wt%):	40.8%	40.8%	30%	30%	30%	30%
Absorber Feed Temp (F):	101	101	115	115	115	104
# Trays of Contact:	20	20	20	20	20	20
Absorber Outlet Temp. (F):	121	121	133	137	146	141
Rich Amine Loading (m AG/m Amine):	0.38	0.38	0.54	0.54	0.48	0.48
Residue Gas Composition:						
CO2 (mole Percent):	1.50%	1.50%	1.77%	1.34%	0.02%	0.03%
H2S (ppm):	4	4	4	4	4	4
Regenerator Conditions:						
Rich Amine Feed Temp. (F):	159	159	180	180	180	174
Reboiler Press (psig):	8	8	11	11	11	10
Reboiler Temp. (F):	236	236	243	243	243	240
Overhead Temp. (F):	205	205	204	204	212	
Reflux Drum Press. (psig):	5	5	8	8	8	8
Reflux Drum Temp. (F):	84	84	93	93	93	68
Reflux Circ. Rate (USGPM):	15.6	15.6	8.9	10.1	20	
Acid Gas Flow Rate (lbmole/hr):	226.5		204	239.5	315	316
Exchanger Data:						
Reboiler Duty (MMBtu/h):	27.1	26.5	19.6	21.3	32.4	36.0
Lean Cooler Duty (MMBtu/h):	17.2	17.2	12.9	13.9	19.4	22.7
Reflux Condenser Duty (MMBtu/h):	8.8	8.8	5	5.7	11.3	12.9
Temperature In (F):	205	205	204	204	212	
Temperature Out (F):	84	84	93	93	93	68
Lean/Rich Exchanger (MMBtu/h):	6.9	6.9	7.4	7.2	7.2	7.2
Lean Temperature In (F):	236	236	243	243	243	240
Lean Temperature Out (F):	198	198	197	200	209	207
Rich Temperature In (F):	121	121	133	137	146	141
Rich Temperature Out (F):	159	159	180	180	180	174
Lean Loading (m CO2/m Amine)	0.009	0.009				0.015
Reflux Drum Overhead:						
Pressure (psig)	5	8	8	8	8	8
Temperaure (F)	84	86	68	93	93	68
Flowrate (MMscfd)	2.1	2.3	1.9	2.2	3.0	2.9
Acid Gas Composition (Mole Percent):						
N2	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
CO2	58.3%	68.6%	65.3%	69.0%	76.3%	76.7%
H2S	38.0%	30.4%	31.2%	27.5%	20.2%	21.5%
C1	0.5%	0.9%	0.0%	0.0%	0.0%	0.2%
H2O	3.2%		3.6%	3.5%	3.5%	1.6%
Total:	100%	100%	100%	100%	100%	100%

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Table #6 - Direct Comparison of Plant #1 & #2 Amine System Operation

- Following values based on direct measurment.

a) Plant #1 Operation Circulating MDEA based Solvent (HS-115).

				Lean Amine Solution				Amine Reboiler South HT-16.06						Amine Reboiler North HT-16.05							
Date	Plant #1 Raw Inlet Rate (E3m3/d)	Plant #1 Raw Inlet Rate (MMscfd)	CO2 % Slip	Lean Soln Circ. (m3/h)	Lean Solution (wt%)	Rich Loading (m AG/m MDEA)	Lean Loading (m CO2/m MDEA)	Temp In (F)	Temp Out (F)	Hot Oil Circ. (m3/h)	Hot Oil Circ. (USGPM)	Hot Oil Flow (lb/hr)	Reboiler Duty (MMBtu/h)	Temp In (F)	Temp Out (F)	Hot Oil Circ. (m3/h)	Hot Oil Circ. (USGPM)	Hot Oil Flow (lb/hr)	Reboiler Duty (MMBtu/h)	Total Reb. Duty (MMBtu/h)	Reboiler Loading (MMBtu/MMscf)
06-Oct	1822.4	64.68	0.85	80.73	32.00%			336	266	204.21	899	449,467	15.33	338	257	172.39	759	379,431	14.93	30.26	11.2294
07-Oct	1637.3	58.11	0.85	79.83	32.00%			334	264	199.02	876	438,043	14.94	338	253	173.83	765	382,600	15.73	30.67	12.6659
08-Oct	1677.5	59.54	0.75	79.23	26.20%			334	264	201.84	889	444,250	15.15	338	253	174.18	767	383,371	15.76	30.91	12.4605
11-Oct	1795.5	63.73	0.90	83.05	32.00%			336	261	196.41	865	432,299	15.88	336	252	173.26	763	381,346	15.68	31.56	11.8839
15-Oct	1690.0	59.98		77.92	32.00%			342	261	158.42	698	348,683	13.72	342	255	155.13	683	341,441	14.33	28.06	11.2260
16-Oct	1764.9	62.64	2.00	75.15	26.90%			338	261	156.29	688	343,995	12.94	338	255	154.93	682	341,001	13.72	26.66	10.2128
22-Oct	1689.1	59.95	1.00	79.58				345	262	135.42	596	298,060	11.99	345	259	190.75	840	419,841	17.63	29.62	11.8563
28-Oct	1890.4	67.10	1.00	79.65	33.40%	0.345	0.005	361	261	125.17	551	275,499	13.49	361	261	178.95	788	393,869	19.29	32.78	11.7268
05-Nov	1704.8	60.51	1.00	72.55	30.80%	0.430	0.008	351	261	145.94	643	321,214	14.05	351	253	135.64	597	298,544	14.10	28.15	11.1640
09-Nov	1653.8	58.70	1.00	70.39	33.00%	0.440	0.008	352	257	146.01	643	321,368	14.90	352	253	136.37	600	300,151	14.44	29.34	11.9942
20-Dec	1753.5	62.24	1.00	80.89	32.00%	0.440	0.008	363	266	162.01	713	356,584	16.84	363	255	164.49	724	362,043	19.00	35.84	13.8206
15-Jan	1956.0	69.43		79.69				363	268	158.24	697	348,287	16.14	363	257	158.16	696	348,111	17.96	34.11	11.7910
04-Feb	1742.8	61.86	1.00	79.53	23.50%			370	261	133.50	588	293,834	15.68	370	255	133.65	588	294,164	16.47	32.14	12.4708
16-Mar	1889.5	67.07	0.73	89.81				373	266	116.50	513	256,417	13.39	373	273	121.53	535	267,488	13.03	26.42	9.4546
17-Mar	1909.4	67.77	1.50	82.71	40.60%	0.380		374	271	114.17	503	251,288	12.57	374	261	114.23	503	251,420	13.90	26.47	9.3735
Average:	1,772	62.9		79.38																30.20	

b) Plant #2 Operation Circulating DEA Solvent.

			Amine Reboiler South						Amine Reboiler North							
Date	Plant #2 Raw Inlet Rate (E3m3/d)	Plant #2 Raw Inlet Rate (MMscfd)	Temp In (F)	Temp Out (F)	Hot Oil Circ. (m3/h)	Hot Oil Circ. (USGPM)	Hot Oil Flow (lb/hr)	Reboiler Duty (MMBtu/h)	Temp In (F)	Temp Out (F)	Hot Oil Circ. (m3/h)	Hot Oil Circ. (USGPM)	Hot Oil Flow (lb/hr)	Reboiler Duty (MMBtu/h)	Total Reb. Duty (MMBtu/h)	Reboiler Loading (MMBtu/MMscf)
06-Oct																
07-Oct																
08-Oct																
11-Oct	1581.4	55.85	410	273	147.79	651	325,286	21.62	410	306	157.72	694	347,142	17.61	39.23	16.8599
15-Oct	1507.0	53.22	390	271	147.24	648	324,076	18.71	403	300	156.94	691	345,425	17.22	35.93	16.2027
16-Oct	1531.1	54.07	412	270	148.12	652	326,012	22.53	412	302	158.05	696	347,868	18.56	41.09	18.2359
22-Oct	1604.3	56.66	419	270	148.26	653	326,321	23.69	419	304	158.26	697	348,331	19.50	43.19	18.2941
28-Oct	1737.1	61.35	412	280	192.17	846	422,967	27.01	412	309	192.49	848	423,671	21.12	48.13	18.8281
05-Nov	1736.4	61.32	401	288	198.33	873	436,525	24.16	401	309	197.39	869	434,456	19.48	43.64	17.0798
09-Nov	1686.0	59.54	412	286	196.91	867	433,399	26.53	412	307	197.50	870	434,698	22.05	48.59	19.5837
20-Dec	1743.6	61.58	419	279	175.04	771	385,263	26.28	419	302	165.14	727	363,474	20.66	46.95	18.2982
15-Jan	1920.7	67.83	415	280	169.62	747	373,334	24.49	415	307	169.66	747	373,422	19.60	44.09	15.5993
04-Feb	1737.5	61.36	424	284	166.10	731	365,586	24.94	424	311	165.00	726	363,165	20.01	44.95	17.5824
16-Mar	1750.2	61.81	404	277	146.73	646	322,953	19.96	404	306	146.40	645	322,227	15.41	35.37	13.7330
17-Mar	1665.9	58.83	409	280	146.37	644	322,161	20.10	409	309	146.82	646	323,151	15.64	35.74	14.5794
	1,683	59.4													42.24	

Energy Savings Calculations:
- Sales Gas Heating Value 1,000 Btu/ft3
- Sales Gas Worth $1.00/GJ.

Date	Estimated Engy Savings (MMBtu/h)	Equiv Fuel Gas (MMscfd)	Energy Savings ($/year)
06-Oct			
07-Oct			
08-Oct			
11-Oct	7.6758	0.23	$88,678
15-Oct	7.8701	0.24	$90,922
16-Oct	14.4287	0.43	$166,693
22-Oct	13.5694	0.41	$156,766
28-Oct	15.3418	0.46	$177,242
05-Nov	15.4907	0.46	$178,962
09-Nov	19.2501	0.58	$222,393
20-Dec	11.1061	0.33	$128,307
15-Jan	9.9774	0.30	$115,267
04-Feb	12.8086	0.38	$147,976
16-Mar	8.9473	0.27	$103,367
17-Mar	9.2695	0.28	$107,090
	12.14	**0.36**	**$140,305**

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Table #7. - Estimated Cost Savings as a Result of Conversion from DEA to Formulated MDEA:

1. Reboiler Energy Savings:

- Assume Sales/Fuel Gas Worth: $1.00 /GJ

Actual Reboiler Duty Savings (From Table Above):	12.0	MMBtu/h
Actual Reboiler Duty Savings (From Table Above):	12.7	GJ/h
Savings:	**$139,102**	**/year (per train)**
Savings:	**$278,205**	**/year (total)**

2. Lean Amine Cooler, Reflux Condenser and High Pressure Amine Pump Energy Savings:

Assume Electrical Energy is Worth: $0.032 /kWh

Shut down one fan in plant #1 amine regen. condenser (HT-16.07):	5.0	hp
Shut down one fan in plant #2 amine regen. condenser (HT-16.56):	5.0	hp
Shut down one fan in plant #1 lean amine cooler (HT-16.03):	5.0	hp
Shut down one fan in plant #2 lean amine cooler (HT-16.73/74):	5.0	hp
Shut down one plant #1 high pressure amine pump (PM-18.09/25) - 350	90.0	hp (est. draw)
Shut down one plant #2 high pressure amine pump (PM-18.53/54) - 300	90.0	hp (est. draw)
Total:	**200**	**hp**
Total:	**149**	**kW**
Savings:	**$41,814**	**/year (total)**

3. Incinerator Fuel Gas Reduction:

- Assume Sales/Fuel Gas Worth: $1.00 /GJ
- Assume Sales/Fuel Gas Heating Value: 1,000 Btu/ft3

Fuel Gas Consumption in Incinerator (HT-15.56) ciriculating DEA:	120,000	scfd
Fuel Gas Consumption in Incinerator (HT-15.56) ciriculating MDEA:	83,000	scfd
Difference:	**37,000**	**scfd**
Savings:	**$11,399**	**/year**

Total Estimated Savings for Both Amine Plants: $331,417 /year

Table #8. - Anticipated Versus Actual Process Changes

- Table below based on operation of one processing train.

	DEA Actual:	(Average From Table #7) UCARSOL HS-115 Actual:
Raw Gas Rate (MMscfd):	60.0	62.9
Circulation Rate (USGPM):	449	350
Circulation Rate Reduction (USGPM):		100
Percent Flow Reduction:		**22.2%**
Acid Gas Rate (lbmol/hr):	315.0	253
Acid Gas Rate (MMscfd):	2.9	2.3
Acid Gas Rate Reduction (lbmol/hr):		61.8
Acid Gas Rate Reduction (MMscfd):		0.6
Percent Flow Reduction:		**19.6%**
Reboiler Duty (MMBtu/h) - Actual Duties From Table #5.	42.2	30.2
Reboiler Duty Reduction (MMBtu/h):		12.0
Percent Reboiler Duty Reduction:		**28.5%**
Lean Amine Cooler Duty (MMBtu/h):	19.4	17.2
Lean Amine Cooler Duty Reduction (MMBtu/h):		2.2
Percent Lean Amine Cooler Reduction:		**11.3%**
Reflux Condenser Duty (MMBtu/h):	11.3	8.8
Reflux Condenser Duty Reduction (MMBtu/h):		2.5
Percent Reflux Condenser Duty Reduction (MMBtu/h):		**22.1%**

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